IV.I Fuel Cell Characterization

IV.I.1 Neutron Imaging Study of the Water Transport in Operating PEM Fuel Cells

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Objectives

- Develop neutron imaging instrument and methods to study water transport in proton exchange membrane (PEM) fuel cells.
- Test and characterize water transport related design and operational parameters of PEM fuel cells.
- Provide industry turnkey, state-of-the-art test facility for fuel cell related research.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- P. Durability
- R. Thermal and Water Management

Approach

- Design methods and instrument for non-destructive detection of water in operating PEM cells.
- Establish neutron imaging user facility for fuel cell testing.
- Test cells of various designs (single and multi-stack).
- Analyze data to quantify water distribution/content and study its impact on fuel cell performance and durability.

Accomplishments

- Established routinely operating neutron imaging test facility for non-destructive evaluation of fuel cells.
- Demonstrated that neutron imaging can distinguish performance differences between flow fields of different designs in operating fuel cells.
- One micro-gram or better water detection sensitivity was achieved.

Future Directions

- Develop fast 3-D imaging capability via coded source technique.
- Enhance facility for imaging of full-scale fuel cell stacks.

- Improve time resolution to 30 frame/second or better for short-stack fuel cells.
- Improve spatial resolution to near 25 micrometers.
- Test design concepts for flow fields and membrane electrode assemblies (MEAs).
- Enhance *non-proprietary* research collaboration with academic institutions/industry.

Introduction

Current PEM fuel cells commonly use perfluorosulfonic acid based membrane technology. During operation, hydrogen (H_2) is brought to the anode side of the MEA, while air is brought to the cathode side of the MEA (Figure 1). H_2 is oxidized to protons and electrons. Protons are driven through the membrane to the cathode side and react with oxygen (O_2) in the air to form water; electrons are conducted externally to provide DC electricity. The control of incoming humidity and the product water within the MEA and gas diffusion layer (GDL) is generally acknowledged as a difficult yet crucial aspect of operating a PEM fuel cell. Too much water within the MEA or GDL layer results in flooding conditions that impede gas diffusion and membrane life; too little water will reduce the membrane proton conductivity, thereby decreasing the cell performance. Many attempts have been made to improve PEM fuel cell water management using data obtained ex situ or via trial-and-errors. However, no satisfactory experimental method has been found to accurately measure the water transport phenomena within the MEA. Proper water management is the key to a stable and long-life PEM fuel cell and must be achieved by properly designing the flow field, the GDL, the MEA, and their interfaces. This requires a fundamental understanding of the ***in situ*** water distribution in an operating fuel cell.

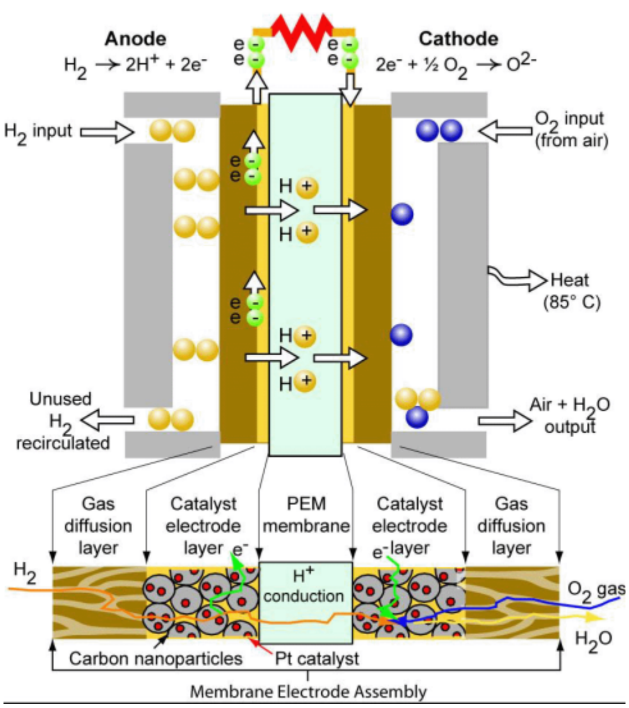

Figure 1. Schematic of a PEM Fuel Cell

Approach

Neutrons are highly efficient in probing complex structures because of their tremendous penetration capability in almost all known materials and due to their unique ability to distinguish different materials with very similar physical properties. They are particularly effective in detecting hydrogenous materials (and other light elements). We have employed charged coupled device (CCD) based digital neutron imaging techniques for *non-destructive, in situ* visualization and quantification of hydrogen transport phenomena and structural anomalies, such as interface de-lamination, in the most common forms of fuel cells that are in development today. We have successfully developed an advanced neutron imaging facility that is capable of employing both absorption and the newly developed 'phase contrast imaging for neutrons'. We plan to utilize both 2-D and 3-D imaging with typically 30 μm spatial resolution and sub-second temporal resolution. In special cases, with proper amplification of the sample (such as the PEM) image, a spatial resolution down to 10 μm or better can be expected. We shall also develop the necessary competence in physics, mathematics, and computational algorithms to describe and interpret the complex interaction process that the neutrons experience.

Results

Non-destructive study of single and multi-stack PEM fuel cell water transport mechanisms is being

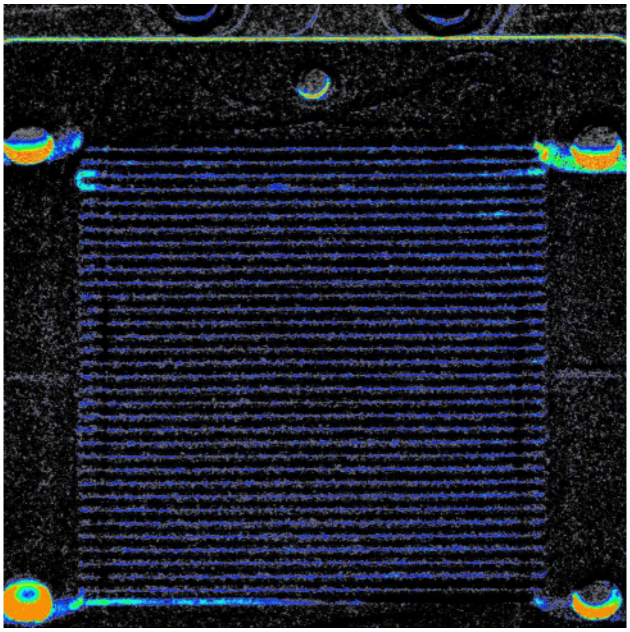

Figure 2. Flow Fields with Blocked Water Channels

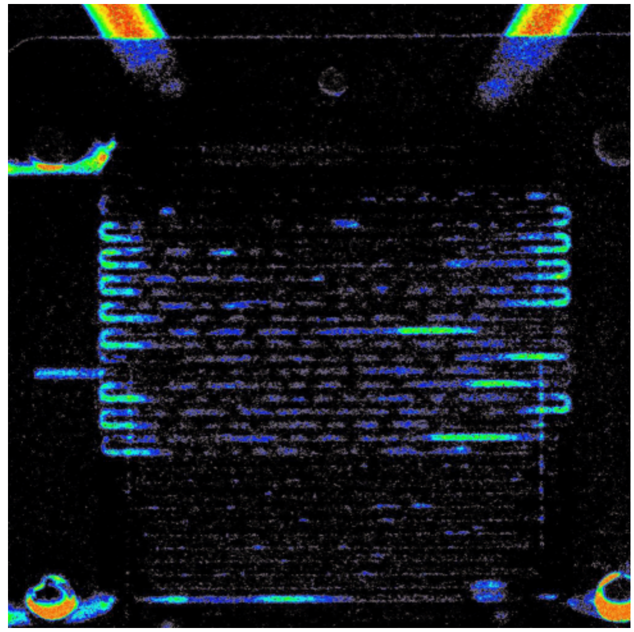

Figure 3. Flow Fields with No Blocked Channels (Operating conditions the same as those in Figure 2)

carried out using the newly developed neutron imaging instrument at the National Institute of Standards and Technology (NIST) Center for Neutron Research (NCNR) reactor. Using neutron imaging methods, visual and quantitative characterization of flow field performance in hydrogen/air dispersion and water removal has been performed. In most cases, a temporal resolution of nearly 100 micrometers and water detection sensitivity of one micro-gram or better was achieved. In linear terms, a water layer of nearly 50 micrometers can be detected with only 1 second of exposure of the PEM to the neutron beam. This is enabling us to observe water dynamics in flow channels with very high sensitivity.

Figures 2 and 3 illustrate the difference in water distribution in two different flow fields in identical operating conditions. Difference in water dispersion capabilities between the two designs is clearly visible.

Figure 4 shows the cumulative water distribution in both cathode and anode flow fields in an operating fuel cell. Uniform hydration hints at a properly functioning MEA.

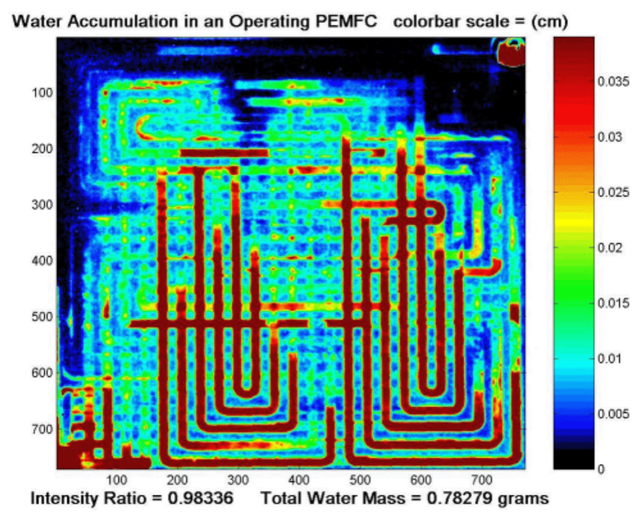

Figure 4. Image of Nearly Uniformly Hydrated Flow Fields and Membrane Assembly

It has been shown that a multi-stack commercial-grade fuel cell stack can be successfully studied by neutron imaging techniques. An advanced data reduction algorithm has been developed and is helping to quantify imaging data to help the fuel cell design and characterization process.

Conclusions

- Performance of various flow field designs now can be characterized by neutron imaging techniques.
- We are able to distinguish and quantify water layers of various thickness (fifty micrometer or better) adequate to influence flow field design parameters.
- Due to enhanced water detection sensitivity, fuel cell performance may be evaluated as a function of water distribution and its absolute content.
- Technical and mechanical improvements of the instrument are allowing study of multi-stack fuel cells.

FY 2004 Publications

1. R. Satija, D. Jacobson, M. Arif and S. A. Werner, "In-situ Neutron Imaging Technique for Evaluation of Water Management System in Operating PEM Fuel Cells," Journal of Power Sources, 129/2 pp. 238-245.

2. T. J. Udovic, M. Arif, C. F. Majkrzak, D. L. Jacobson, T. Yildirim, D. A. Neumann, J. J. Rush, and A. M. Pivovar, "Neutron Metrology for the Hydrogen Economy," in Advanced Materials for Energy Conversion II (D. Chandra, R. G. Bautista, and L. Schlapbach, eds.) The Minerals, Metals & Materials Society, Warrendale, PA (2004) pp. 101-110.

3. T. J. Udovic and M. Arif, "Neutron Probes for the Hydrogen Economy," National Hydrogen Association 14th Annual U.S. Hydrogen Conference and Hydrogen Expo USA, Washington, DC, March 4, 2003. (poster)

FY 2004 Presentations

1. Applications of Neutron Imaging in the Emerging Hydrogen Economy,' International Conference on Neutron Optics Program, Tokyo, Japan, January 18, 2004.

2. 'Neutron Metrologies for the Hydrogen Economy,' GM fuel cell research laboratory, Honeye Falls, NY, March 17, 2004.

3. 'Applications of Neutron Imaging in the Emerging Hydrogen Economy,' Korean Atomic Energy Research Institute (KAERI), Daejeon, South Korea, April 8, 2004.

4. 'Study of Water Transport in PEM Fuel Cells Using Thermal/Cold Neutrons,' Pohang University of Science and Technology, Pohang, South Korea, April 12, 2004.

5. 'Neutron Optical Methods for Applied Industrial Research,' Korean Advanced Institute For Science and Technology (KAIST), Daejeon, South Korea, April 13, 2004.

Special Recognitions & Awards/Patents Issued

1. Top Ten 2003 accomplishments of the DOE Fuel Cell Program chosen by the FreedomCAR Fuel Cell Tech Team.